

## GAS SEAL CONTAMINATION

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## ABSTRACT

Design of seals and sealing systems requires multidisciplinary skills and deep understanding of interactions between the seals and its environment. This paper proposes to present typical gas seals contaminants and corresponding consequences. It will then describe the process typically used to perform the root cause analysis and leading to a proposed fix.

## INTRODUCTION

Dry gas seals are widely used in centrifugal compressors to prevent process gas leakage to external environment and bearing oil migration to the process. Due to their operation under very tight running tolerances, contamination of the dry gas seals can result in catastrophic failures and make them one of the most critical components of the centrifugal compressors.

## DRY GAS SEALS PRINCIPLE

There is no means to have a totally leak free sealing system between two parts in relative movement (*i.e.*, between a static parts and a rotating part; between a housing and a shaft; in pumps, thermal motors...).

There are more or less efficient devices able to limit:

- Leaks
- Friction
- Wear at the interface of the moving parts.

Gas seals are among the most efficient means to reduce process gas leakage to the atmosphere and to reduce wear and friction.

The gas seal is also a reliable means to route effluent leaks to safe areas. The efficiency of the whole process benefits from the gas seal system.

Below is a typical centrifugal compressor cut-away (figure 1) showing the location of the seals. Their location is quite strategic as they are the interface between the inside of the compressor (gas process at high-pressure, high-temperature) and the atmosphere (air and oil mist from the bearing cavity).

Due to the balance line, the gas seal “only” has to deal with the intake pressure of the compressor.

As we will explain later, the gas seal requires a high-quality gas to operate so instead of using the gas present in the balance line, the seals are fed with a clean and dry gas usually taken at the discharge of the compressor.

This gas is dried, filtered, heated if necessary and its pressure lowered to the intake pressure plus epsilon before being injected at the primary port of the seal.

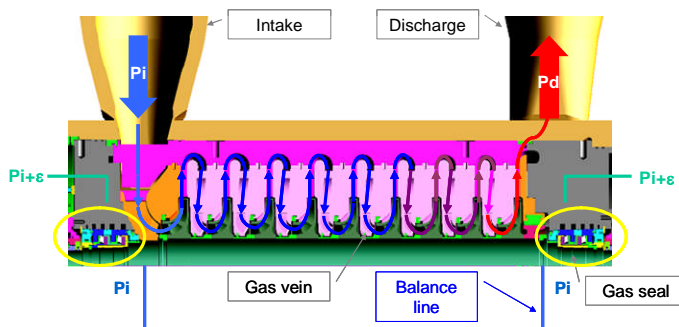


Figure 1. Centrifugal compressor cut-away.

The gas seal principle is simple (figure 2). The leakage (process gas) must be routed to a safe area; therefore, the leakage is forced to pass between a static and a rotating part. The rotating part is a grooved ring driven by the compressor shaft. The static part is a ring facing the rotating ring, but that only has light axial movement.

When rotating, an aerodynamic effect generated by the grooves creates a gap (from 4 to 10 microns) between the rotating and stationary rings. The flow

generated by the pressure differential leaks between the two faces, then the gas leakage is routed to the venting system of the machine (flare) or vent.

Because of the gas film between the faces, a constant gap between the faces prevents the parts from rubbing against each other and makes the gas seal a contact-free device.

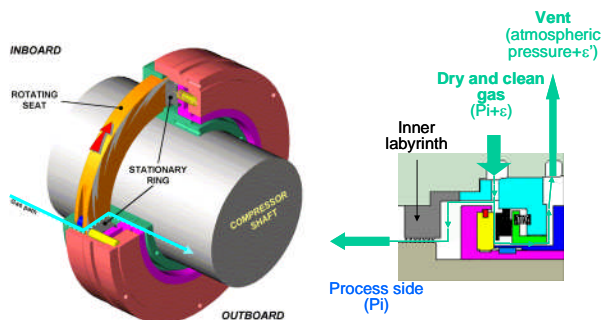


Figure 2. Cut away and cross section of a simplified gas seal.

#### Typical gas seals arrangements

**Tandem gas seal:** Typically used for non-hazardous gases.

The sealing gas is injected at a pressure slightly above the inboard pressure, so that a vast majority (more than 80 percent) of it passes under the inner labyrinth teeth. The remainder (less than 20 percent) passes through the gap created by the lift off effect and leaks to the flare (18 percent) and the last sealing gas residues (2%) leaks through the secondary stage to the vent.

The other important device in the compressor seal is the tertiary seal. It can be a labyrinth or segmented carbon rings. Its duty is to prevent bearing oil mist migration to the seal and sealing gas migration to the bearing oil. This separation is made by a gas leak that prevents the oil from entering the gas seal area on the inboard side and that prevents the sealing gas coming from the secondary stage of the seal from polluting the bearing oil.

So depending on the nature of the separation gas, the gas seal vent may vent a mixture of sealing gas (hydrocarbon) and nitrogen which is acceptable, or a mixture of sealing gas and air.

**Tandem gas seal with intermediate labyrinth:** Used when the process gas is hazardous: *i.e.*, lethal gas, flammable gas, or when condensates at primary seal outlet (figure 3). A buffer gas is needed, such as nitrogen, sweet gas, or fuel gas.

The principle is the same as in the tandem gas seal with the addition of an intermediate labyrinth fed

with a buffer gas (generally nitrogen). This prevents hazardous seal gas from leaking to the atmosphere.

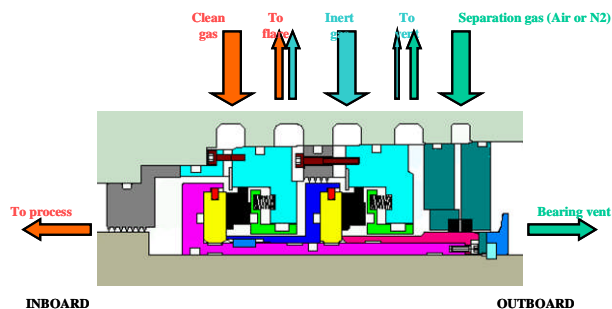


Figure 3. Tandem gas seal with intermediate labyrinth.

**Double opposed (back to back) gas seal:** Used when the process gas is dirty or the sealing pressure is close to atmospheric pressure (figure 4). A sealing gas (typically auxiliary gas) is needed, such as nitrogen, sweet gas, or fuel gas.

The configuration consists of two sealing faces (rotating ring and static seats) in a back-to-back arrangement. The advantage is the lower number of ports required: one for the sealing gas, one for the vent, one for the separation gas, and one for the buffer gas (optional).

Due to the pressure differential between the inboard side of the gas seal and the sealing gas port and between the vent and the sealing gas port, the flow is not symmetrical (a majority of the sealing gas enters the machine).

Generally in low-pressure applications, the available process gas pressure that is not suitable to feed the gas seal, so an alternate source must be considered (*i.e.*, nitrogen, fuel gas).

The nature of the sealing gas must also be compatible with the nature of the process; nitrogen or fuel gas can involve chemical reactions in the process or damage the catalyst.

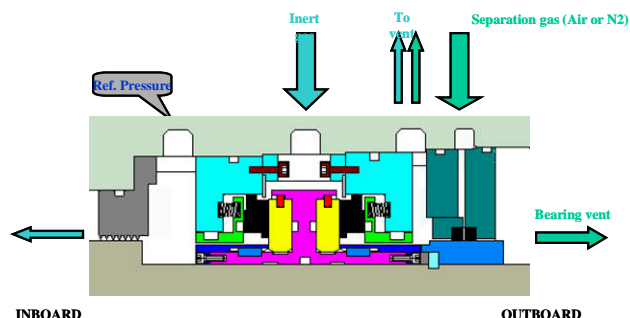


Figure 4. Double opposed gas seal.

## GAS SEAL CONTAMINANTS

### Gas seal interfaces

Dry gas seals interface with the compressor process inner labyrinth, compressor heads, and journal bearings. Gas seals supply, vent and drain; ports are then drilled in the compressor heads and connected to seal support system.

All interfaces with the gas seal and its environment are potential pollution paths. Black arrows in Figure 5 are pollution paths. Pollution occurs:

- On the inboard side if the untreated process gas leaks through the compressor inner labyrinth when the seal gas pressure is lower than the reference pressure
- On the outboard side in the compressor bearing oil when the separation seal is damaged or fails, or there is insufficient separation gas (air or nitrogen)
- In the seal supply ports in the compressor head if sealing gas is not adequately treated in the gas seal system located upstream of the gas seal or if piping is dirty
- In the vent lines if dirt remains or if liquids can be trapped or do not drain.

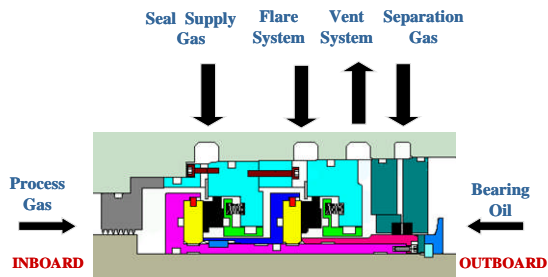


Figure 5. Gas seal pollution paths.

### Contaminant origins and consequences

To avoid gas seal pollution and because of the very thin running gap between rotating and static faces, it is necessary to properly treat sealing gas upstream of the gas seal. Additionally, seal gas quality must be ensured at all times, during all operating sequences such as standby, start-up, running, and shutdown.

Sealing gas is usually required to be free of particles 3 microns (absolute) and larger and 99.97 percent free of liquids.

Contaminants can be either solids, liquids or gaseous.

### Nature of foreign particles

Foreign particles can be:

- Particles from unclean piping (seal supply lines, vent lines)
- Particles from corroded piping, compressor or gas seals components
- Particles in the process gas (figure 6).

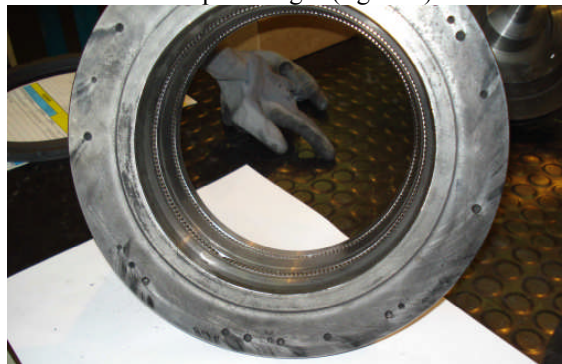


Figure 6. Black powder coming from compressor inner labyrinth.

Pollution can occur because of:

- Poor or non-existent filtration of sealing gas
- Reverse pressurization of the gas seal
- Insufficient flow under the compressor inner labyrinth (figure 7).



Figure 7. Salty deposit on gas seal housing.

### Consequences

Because the running gap between static and rotating faces is around 5 microns, any particle larger than the gap will cause erosion of the faces (figures 8 and 9) leading to an increase in the gas leakage and eventually failure of the gas seal.

Where very thin particles are present, particle accumulation and clogging of the rotating seat grooves

results in a loss of the lift-off effect and again failure of the gas seal.

Another consequence can be damage of the secondary sealing surfaces and more specifically of the balance diameter.



Figure 8. Scratched static seat.

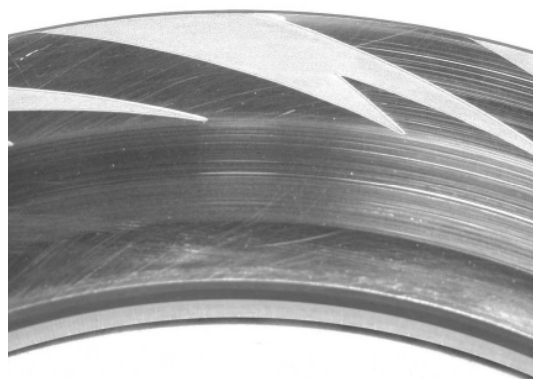


Figure 9. Scratched dynamic seat.

#### *Liquid pollution*

Liquid pollution can:

- Result from bearing oil leakage through the separation seal or migration along the shaft line
- Be present in the process gas stream if there is no, or an inappropriately designed, coalescer in the filtering system
- Be due to the condensation of the sealing gas; seal gas is most commonly taken from the compressor discharge, filtered and then expands as it passes through the gas seal system components, such as the filter, valves, orifices and gas seal faces; as pressure drops, temperature decreases and could result in the seal gas entering in the liquid phase
- Result from contamination by corrosion inhibitors present in the process piping.

#### *Process leading to damage*

Condensates at the gas seal interface will lead to a degradation of the lift-off effect, friction between

static and rotating seats, heat generation, parts deformation, O-rings extrusion, thermal shock on the rotating seat and eventually failure of the rotating and / or static rings. In addition static faces are commonly made of carbon and are therefore subject to blistering due to the porous nature of this material.

#### *Gaseous pollution*

Seal gas is not inherently a pollutant for the seal, assuming it is adequately treated upstream of the gas seal. However, some pollution could occur if a chemical reaction develops:

- Between the seal gas components themselves, for instance polymerization of the seal gas
- Between seal gas components and gas seal / gas seal panel components' materials, such as a reaction between sulfur present in the seal gas stream and nickel present in the rotating ring (figure 10).



Figure 10. Gaseous pollution of rotating ring.

As a contact-free sealing device, the gas seal does not require any maintenance of the cartridge itself. However, in operation, some periodic maintenance of the seal is preferred to check for any pollution, check the condition of the carbon rings and replacement of O-ring which have a limited life span.

This periodic maintenance is an opportunity to control the condition of operation, the efficiency of the panel and take corrective action if required.

As a consequence, providing both gas seal and gas seal system are properly designed, a gas seal failure is always an accident and shall not be considered unavoidable. Thus, a root cause analysis (RCA) of each seal failure shall be conducted. Due to the nature of the gas seal (tight running tolerances, multiple interfaces), such analysis is quite complex and a rigorous methodology needs to be applied.



## ROOT CAUSE ANALYSIS

The root cause of the failure is sometimes obvious (seal gas supply failure, nitrogen supply shortage, abnormal operating conditions). It may be reported by the end user of the machine or be obvious after a gas seal inspection.

The root cause would most likely be difficult to identify, because it must be determined if observed damages are a consequence of the failure or the cause. Thus, a detailed gas seal failure root cause analysis process has been developed in order to address all potential contributing factors and fix the problem for certain.

The process consists of:

- Detailed inspection of the seals / lab analysis of pollution if required
- Collecting a maximum of gas seal environment data / analysis
- Elimination of failure scenario that do not corroborates with data, collecting additional data if required
- Conclusion

### Detailed inspection process

a) When a detailed inspection of a failed seal is conducted, an inspection of the associated opposite gas seal is recommended. Indeed, it is recommended to dismantle the unit and inspect both seals in case of failure for two reasons:

- First, in the case of a gas seal failure, it is very likely that the opposite gas seal has encountered the same pollution/damages.
- Second, it is helpful to have both seals available for inspection because the second gas seal provides clues depending on whether it is not damaged or less damaged than the failed one.

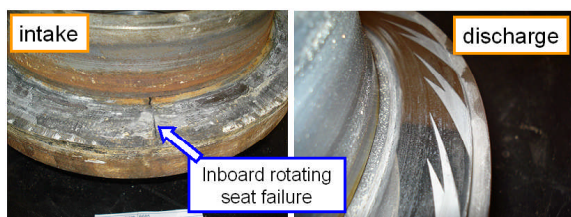


Figure 11. Two opposite seals inspection.

Figure 11 shows two primary rotating seats from the same machine. Because the intake gas seal has failed, it is very difficult to analyze any pollution and draw out any conclusion. Pollution is much more

visible on discharge gas seal and was instrumental in the root cause identification.

b) The gas seal cartridge is inspected externally (figure 12), pictures are taken to detect any external pollution or damage to record areas of pollution and check for any problem concerning the gas seal assembly

c) Then the gas seal outboard housing is removed. This makes it possible to check secondary ring sealing surfaces (static seat and rotating seat).

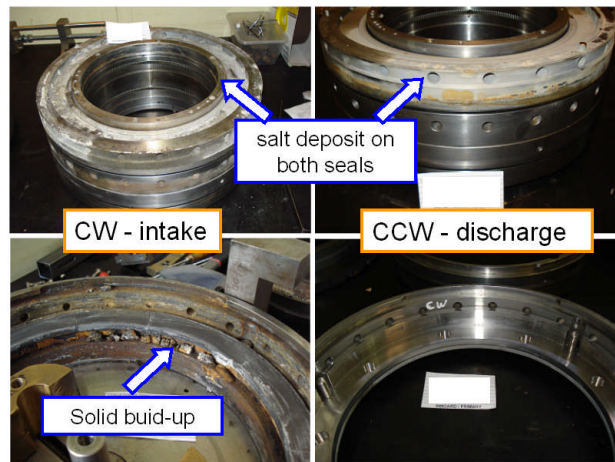


Figure 12. external and internal gas seal inspection.

The outboard side is most likely to be polluted by oil. Location of lube oil should be checked to identify whether lube oil was leaking through the separation barrier or if the source is a gas seal / compressor shaft O-ring problem.

Then the nature and location of any pollution is identified (for example, on the rings, under spring support, on buffer gas port, etc).

In the case of unidentified pollution, samples are taken in order to conduct laboratory analysis. These analyses give some indication on the origin of the pollution. In figure 13, sulfur deposit is detected.

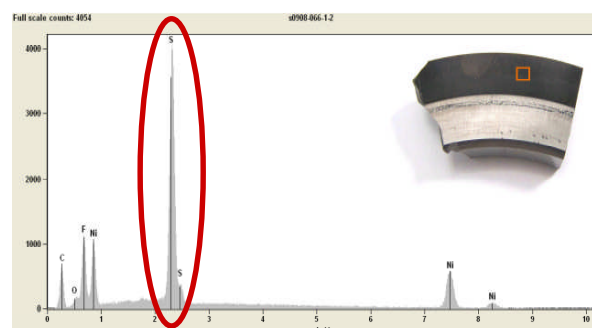


Figure 13. lab analysis of black deposit on rotating seat.

d) The tandem sleeve is extracted in order to open inboard stage; primary ring sealing surfaces are checked for pollution or damages.

e) Then, checking each stage, the condition of the balance diameter is reviewed because it is a very sensitive area that requires a perfect surface finish. At that time, a thorough scrutiny of inboard and outboard housings is also carried out.

f) Finally, the gas seal is fully dismantled in order to check the condition of all O-rings, search for any pollution under static seats and rotating seats and look for any damage on all the parts.

#### Data collection

Investigation of gas seals direct environment is mandatory in order to go further in the RCA. Collecting gas seal environment data is a key phase and is not an easy task because it involves different actors such as:

- End user of the compressor
- Maintenance subcontractor
- Field service representative of seal supplier
- Compressor manufacturer.

A database of all manufactured gas seals has been developed (each gas seal is identified by a serial number). This makes available all original gas seals data (operating conditions, gas analysis, arrangement) for any gas seal.

This database is also used to record all refurbishments or repairs performed on a gas seal after original delivery. This makes it possible to have the whole story of a specific gas seal or all seals of the same service. This information is valuable to a root cause analysis.

It is required to gather the following information from different engineering disciplines:

- Compressor design:
- Compressor head: gas seal ports, draining
- Journal bearing configuration
- Process side: inner labyrinth, balance piston, balance line
- Gas seal system
- Lube oil system.

The sealing gas P&ID (figure 14) is analyzed to check if failure scenarios are compatible with system

design (flow control, pressure control, presence of auxiliary seal gas supply, etc).

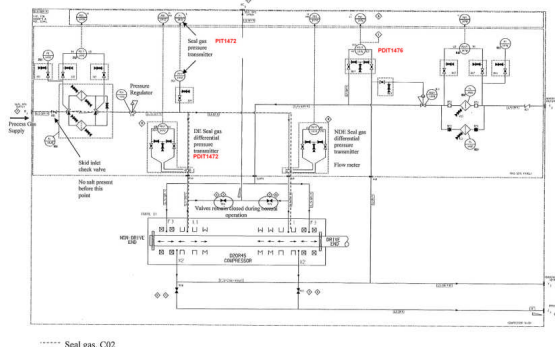


Figure 14. P&ID used for root cause analysis.

Compressor cross section and head drawings (figure 15) are used to check if failure scenarios are compatible with compressor design. Figure 15 shows how water-washes lead to liquid accumulation on the intake sides through the balance line and because of the inlet side is cooler than the discharge.

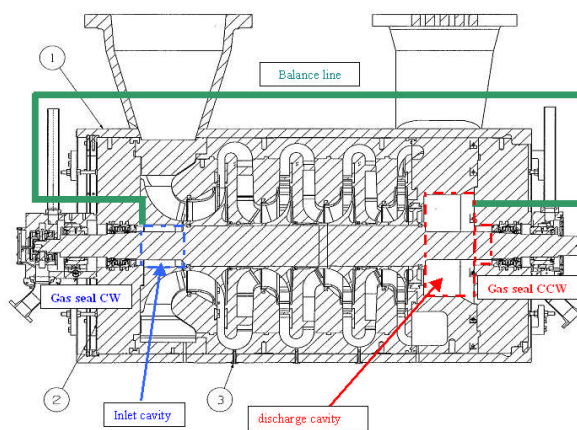


Figure 15. Compressor cross section.

Information from installation site is necessary. All available information from the site related to the seal failure and the seal operation shall be collected. This could include:

- A field report from field service representative recorded observations (visual for example) and measurements taken may help in identifying the failure scenario. On-site observations from client personnel can also be important.
- Trends of operating conditions and gas seal parameters at the time of the failure are analyzed (figure 16).

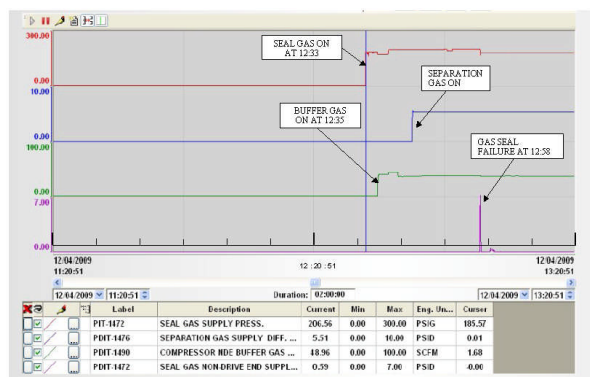


Figure 16. snapshots of trends of gas seal data at failure period.

- Up-to-date gas analysis and operating conditions (inlet and discharge pressure / temperature, settle out pressure, ambient conditions, number of starts/stops, running hours, etc) and operating sequence; these data provide the necessary information for the actual phase map analysis and can confirm if condensates and / or hydrates can form in the gas seal system (figure 17). Condensation / hydrate formation mostly occur during transient phases: start-up / settle out, etc.

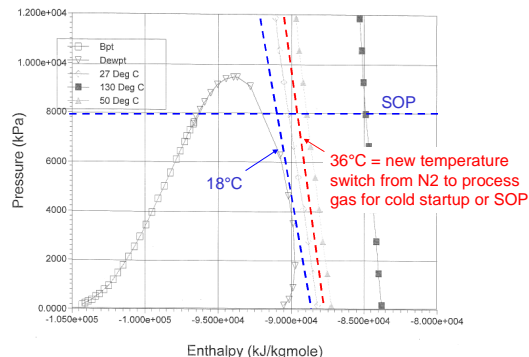


Figure 17. Phase map analysis.

#### Failure scenario

As a result of the inspection, the analysis of gas seal environment data, the failure root cause(s) can usually be identified.

If this is not sufficient, an additional diagnostic tool can be used. A failure mode and effect database has been designed which links any observation collected during gas seal inspection and all data concerning gas seal environment with the potential root causes. This database is used to generate the most likely root cause because of an algorithm that

highlights only the root cause compatible with all provided data.

As an alternative, formal root cause analysis sessions involving compressor product engineers, gas seal OEM representatives, and field representatives are organized using commonly published root cause analysis methods (Ishikawa diagram method, 5-Whys, etc).

## CONCLUSION

As can be seen from the above article, performing a gas seal failure root cause analysis is a difficult task involving several disciplines, several actors and can be a lengthy process.

Root cause analysis can lead to gas seal or system design adjustments such as:

- Implementation of a conditioning skid: heater, scrubber, filter, mercury trap, booster
- Modification of operating sequences
- Addition of heat tracing

Finally, it should be mentioned that these design adjustments may help improving gas seal system reliability but it can also be improved by:

- Training the on-site operators to provide in-depth knowledge of the seal and sealing systems specificities
- Ensuring gas seals installation and dismantling from the compressor is done by trained personnel
- Implementing periodic checks on the system, such as weekly draining of low points, visual check of vents.

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